A DIGITAL COMPUTER PROGRAM FOR REAL-TIME COMPUTATION OF RADAR CROSS SECTION ON A DYNAMIC TARGET

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THESIS

A DIGITAL COMPUTER PROGRAM FOR REAL-TIME COMPUTATION OF RADAR CROSS SECTION ON A DYNAMIC TARGET

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A Digital Computer Program for Real-Time Computation of Radar Cross Section on a Dynamic Target

by

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ABSTRACT

This thesis describes the design and use of a computer program for the real-time computation of radar cross section of a dynamic target using the NIKE/AJAX radar. The program is written specifically for use on the SDS-9300/CI-5000 hybrid computer system but could be adapted to other data processing systems. The input data consists of transmitted values of range, bearing and elevation from the NIKE/AJAX radar digital data buffer and sampled values of automatic gain control voltage and logrithmic amplifier output voltage from the NIKE/AJAX radar. Outputs include values of target range, bearing, elevation, velocity, heading, angle, X and Y positions, instantaneous values of target cross section and averaged values of target cross section. These computed quantities are converted into scaled voltages which are transmitted to displays in the radar laboratory. Although the system at this time provides only a basic real-time capability, it provides a foundation for further work planned in this area.

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I. INTRODUCTION

Radar cross sections for various simple geometric objects have been calculated and experimentally verified. Cross sections for more complex targets such as fixed and rotary-wing aircraft have been measured. This is usually done by constructing a scale model of the target. The model is then placed in an anechoic chamber and illuminated with appropriate RF energy at a frequency scaled to the model. The aspect of the model with respect to the sensor is then varied and the backscattered energy is recorded. Cross section as a function of aspect and frequency is obtained from this data.

The examination of cross sections of geometric objects is useful in an academic approach to diffraction phenomenon but bears little significance to the engineering of a radar system. Measurement of cross sections of models is, at best, a first-order approximation to the determination of backscatter cross section. The model is static and rests in a controlled environment. A dynamic target does not show a smooth, modelled shape. Further, backscatter is modified by turbine and propeller modulation and changes in diffraction of the wave fronts due to airfoil control surfaces and fuselage vibration. Since target size has a pronounced effect on the determination of radar system performance, it is then necessary that cross section be measured on dynamic targets.

One method for dynamic measurement of cross section uses a ground-based fire control radar. The radar system is calibrated by tracking a six-inch metal sphere lofted by a helium-filled balloon prior to tracking the target whose cross section is to be measured. AGC voltage and range are recorded. This calibration permits many of the parameters in the

radar range equation to be considered as a single term. A target is tracked immediately following calibration, and AGC voltage and range are recorded. Cross sections for the target can be calculated by comparing ranges to target and sphere for equal AGC voltages. While this method is a definite improvement over static measurement, disadvantages still exist. The AGC circuit serves to integrate the target data so that only mean cross sections can be calculated. Instantaneous data is lost.

Meyett [Ref. 2] and Cunningham [Ref. 3] designed a system that computed instantaneous values of target cross section using the MK 25 fire control radar. The voltage output of the radar's boxcar generator was recorded on magnetic tape as an indication of target signal strength. Target range was also recorded. When sufficient data was collected, the magnetic tape was processed on the SDS-9300/CI-5000 hybrid computer system as described in Ref. 2. Instantaneous values of target cross section were computed and displayed. While this method is a definite improvement over the two previously mentioned methods, the computation of the cross section data was not done on a real-time basis and could not have been immediately useable to a radar operator.

The computer program described by this paper computes values of target cross section on a real-time basis. The computations are based on sampled values of AGC voltage and LOG IF amplifier voltage. The AGC computations give an integrated cross section value based on several target return signals. The LOG IF amplifier computations give cross section values on an instantaneous basis. Cross section values of both types are averaged to give an effective target cross section over a set of samples. The data is immediately available to the radar operator for operational use.

Range, bearing and elevation are transmitted to the computer system once a second. Values of target altitude, target speed, target velocity, target heading and target X and Y position are computed from this information and transmitted back to the radar laboratory. The radar operator can use this information to correlate changes in computed values of target cross section with changes in target aspect.

This thesis project was undertaken in conjunction with another, Ref. 1, whose objective was to get the target data to the computer system and display the computed values of target parameters and cross section data.

II. THEORY

A. AGC CROSS SECTION COMPUTATION

The concepts for measurement of radar cross section on an instantaneous basis using AGC voltage are similar to those outlined by Cunningham [Ref. 4]. The fire-control radar that is used in the measurement is first calibrated by tracking a metallic sphere of known radar cross section. A functional relationship between radar range and signal strength can be found since the sphere presents a constant aspect, and its cross section is known. Values of sphere range and AGC voltage are recorded. Selected values of these quantities are put into a curve-fitting routine to determine the coefficients of the polynomial describing the curve of AGC voltage versus range. The curve-fitting routine used in LSQPL2, an IBM-360 routine which has been adapted for use on the SDS-9300. This subroutine performs a least-squares fit to the fifth order and outputs the coefficients of the polynomial relating AGC voltage to range for the calibration track. When a target is tracked following calibration, values of AGC voltage and target range are sent to the SDS-9300 computer. The value of target AGC voltage is used to enter the polynomial relating AGC voltage and range for the calibration track. The polynomial then gives range to the sphere for the value of calibration track AGC voltage equal to target AGC voltage. Radar cross section for the target is found by forming a ratio of radar range equations.

Each range equation may be reduced to a relatively simple form if measurement of the target immediately follows calibration and atmospheric effects are neglected. System parameters such as transmitted power, noise figure, system losses and antenna gain may be assumed to remain constant

by proceeding in this manner. Let C represent those terms which remain constant between calibration and measurement. The simplified form of the radar range equation is written as:

$$R^4 = C\sigma/S \tag{1}$$

where: R = radar range, meters

S = received signal power, watts

σ = radar cross section, meters^2

C = constant, meters^2-watts.

In the NIKE/AJAX radar, the AGC voltage is more conveniently measured than actual signal power at the receiver. The functional relationship between the voltage and signal power is not linear because of the circuitry involved, but may be generally written:

$$S = f(V) \tag{2}$$

where: V = AGC voltage.

Equation (1) may be rewritten:

$$R^4 = C\sigma/f(V) \tag{3}$$

and further, let:

$$B(V) = C/f(V) \tag{4}$$

then Equation (1) becomes:

$$R^4 = B(V)\sigma \tag{5}$$

or:

$$B(V) = R^4/\sigma \tag{6}$$

and:

$$B(V_s) = R_s^4/\sigma_s \tag{7}$$

where Equation (7) has been subscripted for the calibration data on the sphere. Since R_s and V_s are measured and σ_s is known, there exists a value of the function which describes all system parameters. If R_s and V_s are continuously recorded then the lumped parameter function B(V) becomes continuous. For the calibration track the sphere radar cross section is calculated:

$$\sigma_s = r^2\pi \tag{8}$$

where: r = radius of sphere, meters.

An identical form of Equation (7) is written for the target to be measured:

$$B(V_t) = R_t^4/\sigma_t \quad . \tag{9}$$

Since the same radar system tracks both sphere and target, $B(V_s) = B(V_t)$ provided $V_s = V_t$. Substituting $B(V_s)$ for $B(V_t)$ in Equation (9):

$$R_s^4/\sigma_s = R_t^4/\sigma_t \tag{10}$$

or:

$$\sigma_t = R_t^4\sigma_s/R_s^4 \quad . \tag{11}$$

Since $B(V_s)$ must equal $B(V_t)$ for $V_t = V_s$, there exists a value of R_s for each value of V_t and R_t. The value of radar cross section of the sphere is known. Target cross section may be found directly for each value of V_t.

B. LOG IF AMPLIFIER CROSS SECTION COMPUTATION

The output voltage of the logrithmic IF amplifier as seen by the computer has been plotted versus input power to give an operating characteristic curve which is displayed in Figure (1). The input power is defined as power relative to 1 milliwatt (dBm) PREL. It is also the received power from the target, PREC. Relative power is related to the output voltage by the following relationships for the two areas of the curve:

$$PREL = -5.45V - 77.5, \quad V > -10.5 \text{ volts} \tag{12}$$

$$PREL = -(V+10.5)20 - 20, \quad V < -10.5 \text{ volts} \tag{13}$$

PREL also has the following relationship to PREC when both are in milliwatts:

$$PREL\ (dBm) = 10\log_{10}(PREC) \tag{14}$$

$$PREL\ (dBm) = 10(0.434)\log_e(PREC) \tag{15}$$

$$\log_e(PREC) = PREL/4.34 \tag{16}$$

$$PREC = e^{(PREL/4.34)} \tag{17}$$

Received power may also be determined from (is also defined by) the following relationship under conditions where propagation is essentially the same as in free space:

$$PREC = P_t G A \sigma_t / 4\pi^2 R_t^4 = K\sigma_t / R_t^4 \tag{18}$$

where: R_t = target range, meters

G = antenna gain

A = effective antenna aperture, meters^2

P_t = transmitted power, watts

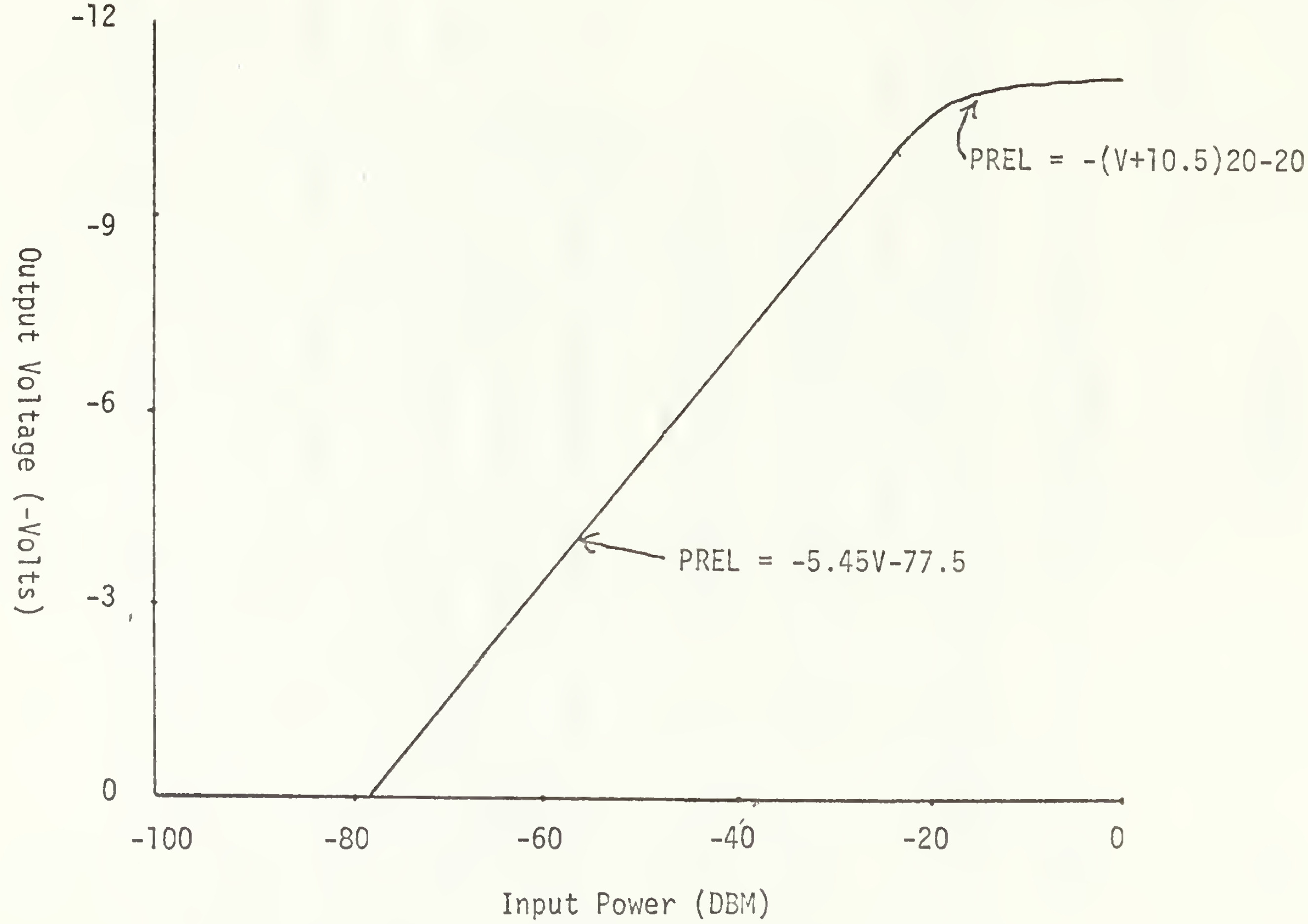

Figure (1). LOG IF Amplifier Operating Characteristic Curve

σ_t = target cross section, meters^2

K = system constant, meters^2-watts.

therefore:

$$\sigma_t = PREC(R_t^4)/K \quad . \tag{19}$$

From Equation (17):

$$\sigma_t = R_t^4 e^{(PREL/4.34)}/K \quad . \tag{20}$$

Finally from Equations (12) and (13), using the relationship between LOG IF amplifier output voltage and relative power:

$$\sigma_t = R_t^4 e^{((-5.45V-77.5)/4.34)}/K \tag{21}$$

$$\sigma_t = R_t^4 e^{((-(V+10.5)20-20)/4.34)}/K \quad . \tag{22}$$

The value of K is calculated by tracking a metallic sphere of known cross section. Values of LOG IF amplifier output voltage versus range are recorded. Since σ_t, R_t and V are known, K can be calculated. Once K is calculated, it can be put into Equations (21) and (22) and used to calculate target cross sections. K has a value of approximately 10^{10} for the NIKE/AJAX radar. K will vary depending on the radar's PRF and system performance and should be recalculated on a regular basis and after any system maintenance procedures that greatly affect system performance.

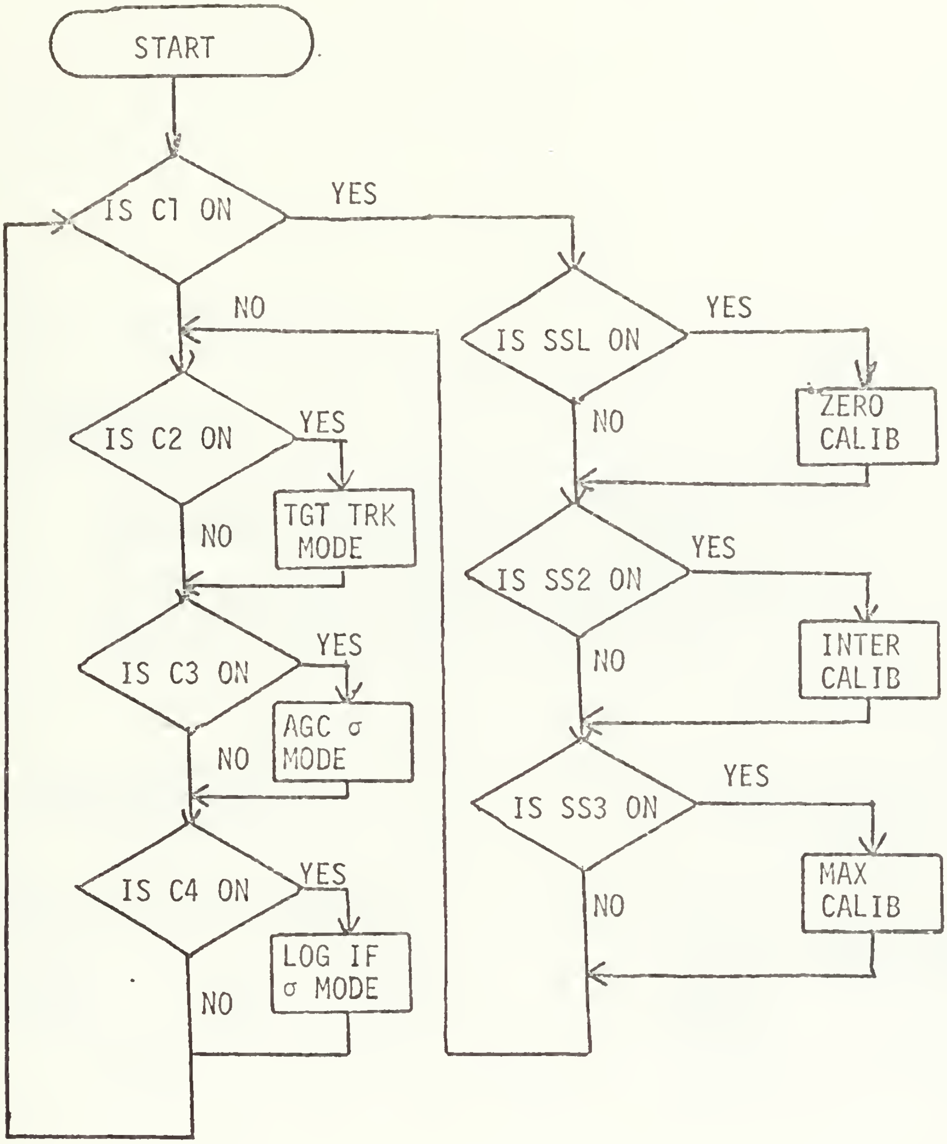

Figure (2). Program Flow Chart

Output Logic

1. If the sum of the inputs is greater than zero, then coo = -6V (on) and $\overline{coo} = 0_V$ (off)

2. If the sum of the inputs is less than zero, then coo = 0_V (off) and $\overline{coo}$ = -6V (on)

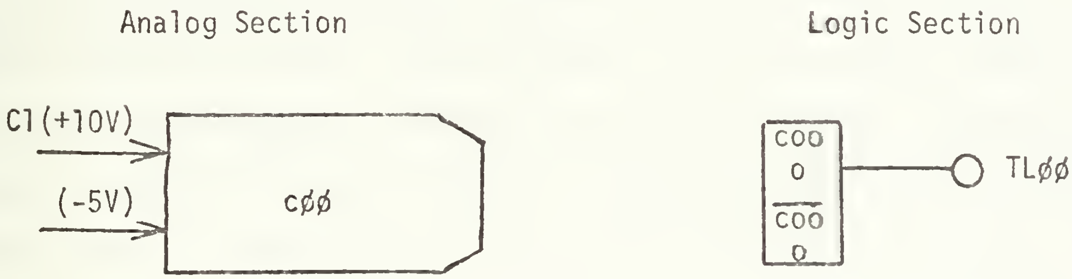

Figure (3). Typical Control Switch Connection

III. PROGRAM DESCRIPTION

The program description is divided into the functional areas of the program preceded by a description of certain aspects which are common to all functional areas.

A. GENERAL

1. Program Transportation

Transportation between the functional areas of the program is accomplished by means of four control switches on the NIKE/AJAX digital data buffer. The radar operator selects the system mode of operating by energizing one of these switches. This sends a ten-volt signal to the CI-5000 analog computer. The ten-volt signal is compared with a minus-five-volt signal in a comparator on the analog section of the CI-5000 and causes the output of the comparator on the logic section to change from false to true. The true output of the comparator, minus-six-volts, is patched to a test line on the logic section. The digital computer sequentially samples the test lines corresponding to the control switches until it finds one that is energized. The mode of operation corresponding to the energized control switch is then initiated. Selection of various options within the functional areas is accomplished by a selector switch on the data buffer. The determination as to which position of the selector switch is energized is accomplished in the same manner as for the control switches. A program flow chart is contained in Figure (2). A typical control switch connection is depicted in Figure (3).

2. Interrupts

The program uses three interrupt signals. The interrupts cause the normal operation of the program to be halted until the subroutine

associated with the energized interrupt is processed. The interrupt signals are ten-usec, minus-six-volt signals applied to the interrupt trunks on the logic section of the CI-5000 analog computer. The interrupts are armed and disarmed by "ANDing" them with minus-six-volt logic signals from setline terminals on the logic section. These logic signals are set by machine language instructions to the SDS-9300 digital computer and are the fastest means of arming and disarming interrupts. The logic signal and the interrupt signal are patched into a two-input NAND gate whose output is patched into the input of a one-input NAND gate. The output of the one-input NAND gate is patched to an interrupt trunk. The net effect is to AND the minus-six-volt logic signal and the minus-six-volt interrupt signal. If the logic signal is present, the interrupt signal goes through the two NAND gates to the interrupt trunk. If the logic signal is absent, no signal goes to the interrupt trunk. The patching of a typical interrupt signal is illustrated in Figure (4).

B. CALIBRATION MODE

The calibration mode allows the radar operator to check the calibration of various meters and displays in the radar laboratory. The operator selects this mode of operation by energizing control switch C1. There are three different calibration routines which can be selected through the selector switch on the data buffer. Each of these routines sends a different voltage for each target parameter that is displayed at the radar. Each target parameter is assigned a numerical value and these values are then converted from digital to analog values. The D/A output trunks are then patched to the appropriate trunk lines leading to the radar laboratory. The listing of the various parameters and associated voltages and the quantities represented by these voltages is contained in Table (1).

Logic

1. If both the -6V interrupt signal and the -6V logic signal are present at the inputs to the first NAND gate, its output is false (0V). The output of the second NAND gate is then true (-6V). This effectively AND's the logic signal with the interrupt signal.

2. If the -6V logic signal is removed by the ADS-9300, the output of the first NAND gate is true (-6V) and the output of the second NAND is false (0V). This effectively disarms the interrupt.

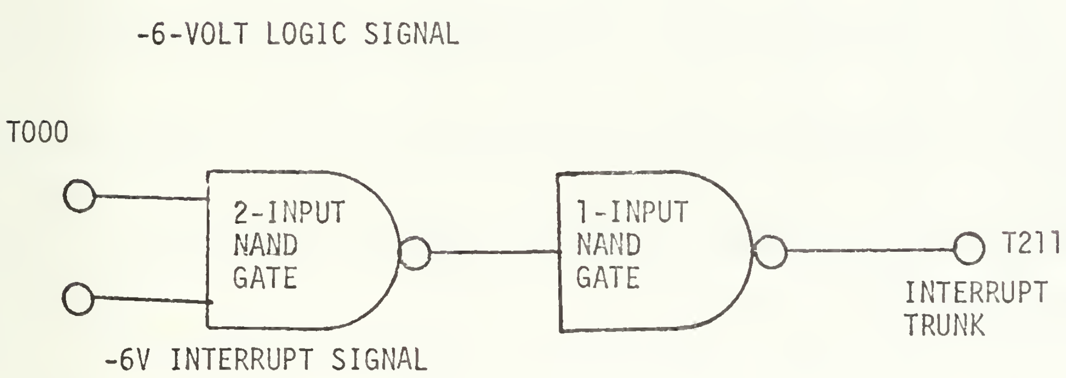

Figure (4). Typical Interrupt Connection

CALIBRATION ROUTINE	ZERO		INTERMEDIATE		MAXIMUM	
TARGET PARAMETERS	VOLTS	VALUES	VOLTS	VALUES	VOLTS	VALUES
INSTANTANEOUS CROSS SECTION	0	-	10	$50m^2$	50	$250m^2$
AVERAGE CROSS SECTION	0	-	10	$50m^2$	50	$250m^2$
TARGET VELOCITY	0	-	25	250KTS	50	1000KTS
TARGET HEADING	0	-	36	360°	-	-
TARGET X-POSITION	0	-	3	75Kyd	-3	-75 Kyds
TARGET Y-POSITION	0	-	3	75Kyd	-3	-75 Kyds
TARGET ALTITUDE	0	-	10	5KFT	50	25KFT
TARGET ANGLE	0	-	36	360°	-	-

Table (1). Calibration Mode Settings

C. TARGET TRACKING MODE

The target tracking mode of operation is entered by energizing control switch C2. The description of this mode of operation is divided into two parts: (1) data transmission and (2) computation of target parameters.

1. Data Transmission

The NIKE/AJAX radar digital data buffer was originally designed to interface with a specific piece of U.S. Army fire-control equipment. A means had to be devised to interface the data buffer with the SDS-9300/CI-5000 hybrid computer system.

A 1-hz clock signal on the logic section of the CI-5000 analog computer is used to enable delay flop (DF)12 for ten-usec. The true output of DF12 is used to enable digital/analog switch 07 on the analog section of the CI-5000 which transmits a ten-usec, five-volt system synchronization pulse to the data buffer. The generation of the system synchronization pulse is depicted in Figure (5). Upon reception of this pulse, the data buffer interrogates the radar's range, bearing and elevation units and converts the analog range, bearing and elevation quantities into 18-bit data words. Each bit of the data words has its own bit weight. The bit weights are read into the integer data arrays NR(18) and NDEG(18) for range and bearing/elevation computations respectively. The data buffer sends a five-volt data-ready signal to the hybrid computer system when the data conversion is completed. The five-volt data-ready signal is compared with minus-three-volts in comparator C12 on the analog section of the CI-5000. The false output of C12 on the logic section of the CI-5000 is patched to the clock input of DF06 whose enable input has been grounded. The arrival of the five-volt data-ready signal causes the false output of C12 to

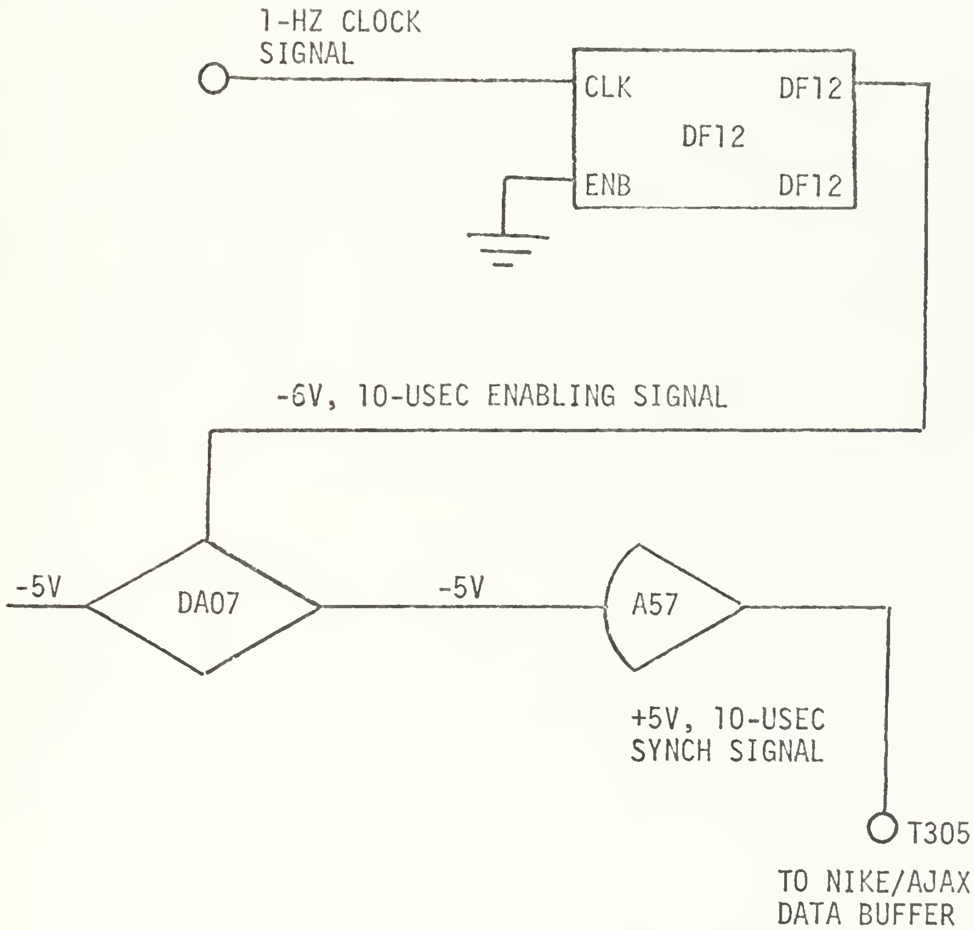

Figure (5). Generation of 1-hz System Synchronization Signal

change from minus-six-volts to zero-volts and this triggers DF06 which stays enabled for 0.19 seconds. Its false output (zero-volts) is patched to the enable input of DF07 and DF10 and allows them to be triggered by a signal to their clock inputs that changes from minus-six-volts to zero-volts. This is accomplished by a 100-hz clock signal on the logic section of the CI-5000. DF07 is set to stay enabled for five ms. and its true output is used to enable digital/analog switch 06. The combination of the 0.19-second enabling signal and the 100-hz clock signal allows digital/analog switch 06 to transmit 19 five-volt data-shift pulses to the data buffer. The reception of the first data-shift pulse causes the data-ready signal to be turned off and the first of the 18 data bits for the range, bearing and elevation words to be transmitted to the hybrid computer system. The nineteenth data-shift pulse causes the digital data buffer to be reset for the next data transmission cycle. DF10 is set to remain enabled for ten-usec. Its true output is patched to interrupt trunks 52 and 53. The generation of these signals is depicted in Figure (6).

2. Computation Of Target Data

When the target tracking mode is entered by energizing control switch C2, the digital computer arms interrupt 52 which is connected to subroutine SHIFT1. This interrupt signal is generated by DF10 and occurs whenever a data-shift pulse occurs. Every time interrupt 52 occurs, SHIFT1 causes the test lines associated with range, bearing and elevation to be tested for the presence of a data bit. If a data bit is present on one of the lines, the appropriate bit weight is added to the range, bearing or elevation word. By having the bit weights in integer form, the testing and computation sequence for all three data lines is approximately 3.5

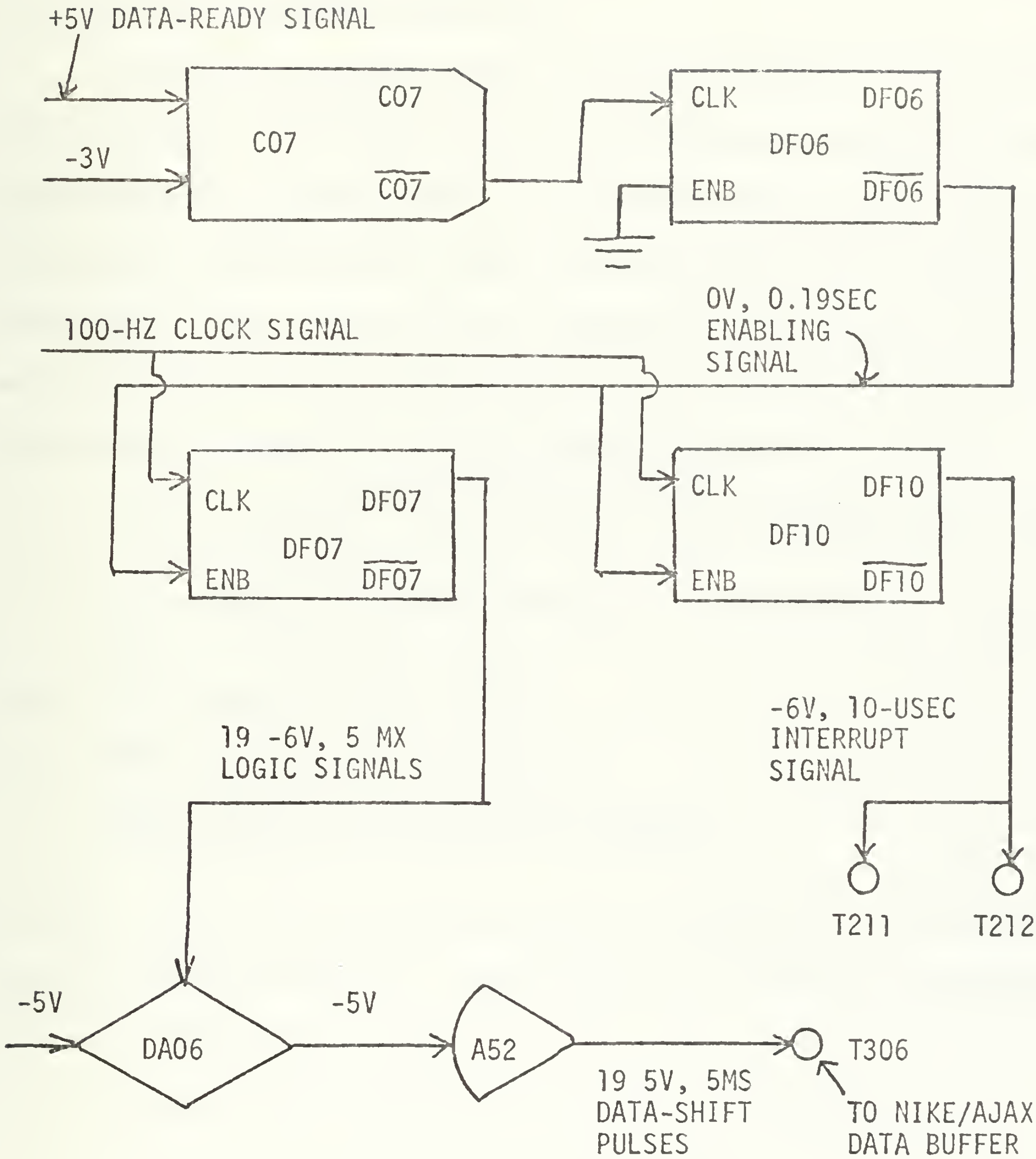

Figure (6). Generation of Data-Shift Pulses and Associated Interrupt Signals

times faster than if floating-point numbers were used. Interrupt 52 is disarmed after the nineteenth data-shift pulse has occurred. The program now begins to process the target data.

The values of target range, bearing and elevation are scaled for maximum values of 100,000 yards, 360° and 90° respectively. Any scaling computation has to consider that the SDS-9300 digital computer multiplies by a factor of 100 any value that is being converted from digital to analog form. These values are not transmitted to the radar laboratory but are available to the computer operator for use in trouble-shooting data transmission problems and for general observation.

Target altitude in feet above sea level is computed as follows:

$$ALT = 3.0(RNG^2COS^2(ERAD)/1400000.0 + RNG(SIN(ERAD))) \quad (23)$$

where: ALT = target altitude, feet

RNG = target slant range, yards

ERAD = target elevation angle, radians.

The first term on the right-hand side of the equation is a correction factor for earth curvature. Target altitude is scaled for a maximum value of 50,000 feet.

Target X and Y coordinates are computed as follows:

$$TXN = RNG(COS(ERAD)SIN(BRAD) \quad (24)$$

$$TYN = RNG(COS(ERAD)COS(BRAD) \quad (25)$$

where: TXN = new target X-coordinate, yards

TYN = new target Y-coordinate, yards

BRAD = target bearing angle, radians.

The old values of target X and Y coordinates are subtracted from the new values to get the differences in target X and Y position, XDIF and YDIF. The old values of target X and Y coordinates are then replaced by the new values for the next computation cycle. Target X and Y coordinates are then scaled for presentation on the X/Y plotter in the radar laboratory. One inch equals 25,000 yards on this plotter which contains a scaled chart of the Monterey Bay area and gives target position with respect to local geographical features.

Target velocity is computed as follows:

$$TV = TD(3600.0)/2025.3 \tag{26}$$

where: TV = target velocity, knots

3600.0 = seconds/hour

2025.3 = yards/nautical mile.

Target velocity is scaled for a maximum value of 2000 knots.

Target heading is computed in the following manner. First, the absolute value of YDIF/XDIF is determined. Then the ARCTAN of this value is computed and designated as Y. This determines the angle between XDIF and YDIF. The program next checks values of YDIF and XDIF to determine target heading. If XDIF is positive, the target heading, TH, lies between 0° and 180°. If YDIF is positive, TH = 90° -Y. If YDIF is negative, TH = 90° +Y. If XDIF is negative, TH lies between 180° and 360°. If YDIF is positive, TH = 270° -Y. If YDIF is negative, TH = 270° +Y. Target heading is scaled for a maximum value of 360°

Target angle is the final target parameter computed. Target angle is the relative bearing of the tracking radar from the target and gives the target aspect with respect to the tracking radar beam. If the

target bearing, BD, is less than 180°, LOS (the line of sight from the target to the radar) = BD +180°. If BD is greater than 180°, LOS = BD -180°. If target heading is less than LOS, TA (target angle) = 360° -TH +LOS. Target heading is scaled for a maximum value of 360°. Figure (7) depicts the computation of target heading and target angle.

The scaled values of target range, bearing, elevation, velocity, heading, angle, X-position, Y-position and altitude are transmitted on D/A channels 3-11 respectively. The program then sequentially samples the test lines associated with the other control switches to determine if the radar operator has chosen another mode of system operation. If not, the program returns to the target tracking mode of operation.

D. AGC CROSS SECTION COMPUTATION MODE

The AGC cross section computation mode is entered by energizing control switch C3. The program arms interrupt 53 which is connected to subroutine SHIFT2. SHIFT2 updates the value of target slant range for computation of correct cross section values. Interrupt 53 occurs in coincidence with the 19 data-shift pulses. Whenever a data-shift pulse occurs, SHIFT2 causes the range data line to be tested for the presence of a range bit. If one is present, the appropriate bit weight is added to the range word. When the range word has been updated, the program starts computing AGC cross sections.

The program calls subroutine AGC 6000 times. The approximate execution time of this subroutine is 800-usec and gives a computation frequency of approximately 1250-hz. Due to the fact that the AGC voltage is the result of the integration of several target signal pulses, it is not necessary to time the calling of this subroutine with an interrupt signal generated by the radar's range gate. The subroutine calls a machine

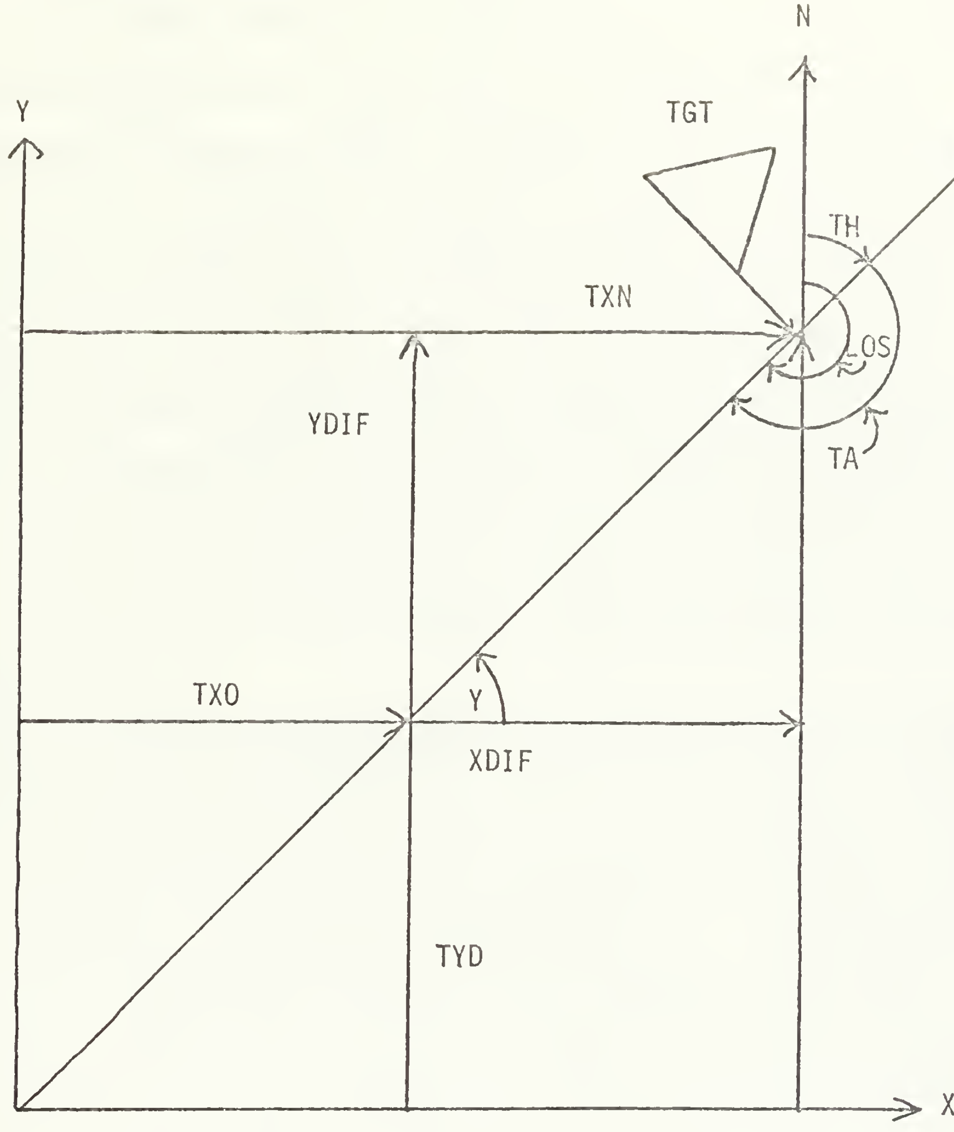

Figure (7). Target Heading and
Target Angle Relationships

language subroutine ADODA1 for the sampling of AGC voltage and the display of computed cross section values. It is necessary to use a special method of D/A and A/D conversion due to the relative slowness of the regular routines available for these purposes. ADODA1 performs a D/A conversion of the value stored in the digital computer's A register. Upon completion of this conversion, ADODA1 performs an A/D conversion on the analog voltage at A/D channel #1 and stores this value in the computer's A register. It was necessary to design subroutine AGC around ADODA1 to make maximum use of its speed in performing the data conversions. ADODA1 takes approximately 250-usec to accomplish the two conversions. Use of the normal conversion routines in the digital computer's resident library would take approximately two ms.

When AGC is called, it first returns the sampled value of AGC voltage to its normal value by multiplying it by a factor of 100. This is necessary due to the fact that the digital computer divides by a factor of 100 any value on which it is performing an A/D conversion. The subroutine next computes the various powers of AGC voltage needed for the curve-fitting polynomial which determines the constructive range to the sphere for the sampled value of target AGC voltage. When these powers of AGC voltage are computed, the subroutine combines them with the coefficients determined previously from the curve-fitting routine to arrive at the value of constructive sphere range. The six coefficients have been read into array B(6). The program uses this value along with target slant range and sphere cross section to compute target cross section as follows:

$$\sigma_t = R_t^4 \sigma_s / R_s^4 \tag{27}$$

where: σ_t = target cross section, meters^2

σ_s = sphere cross section, meters^2

R_t = target slant range, yards

R_s = constructive sphere range, yards.

The computed value of target cross section is scaled for a maximum value of 500 square meters. The cross section value is added to a summing function, SIGSUM(1), for use in computing an average value of target cross section. The computed value of target cross section is then loaded into the digital computer's A register and subroutine ADODA1 is called. The computed value of target cross section is then sent out on D/A channel #1 and is sent to an oscilloscope in the radar laboratory. This allows viewing of the fluctuations in instantaneous target cross sections. ADODA1 then samples the AGC voltage line. The sampled value of AGC voltage is then stored for use in computing the next instantaneous cross section value when subroutine AGC is called again.

When subroutine AGC has been called 6000 times by the program, the average value of target cross section is computed by dividing SIGSUM(1) by 1000. This value is converted to an analog voltage on D/A channel #2 and is displayed on an average cross section meter in the radar laboratory. The program then sequentially samples the test lines associated with control switches C4, C1 and C2 to see if the radar operator has chosen another mode of operation. If this is not the case, the program returns to the AGC cross section computation mode of operation.

E. LOGRITHIMIC IF AMPLIFIER CROSS SECTION COMPUTATION MODE

The LOG IF amplifier cross section computation mode is entered by energizing control switch C4. The program arms interrupt 53 which is

connected to subroutine SHIFT2. Interrupt 53 and SHIFT2 update the value of target slant range to ensure correct computation of target cross sections. This is done in the same manner as in the AGC cross section computation mode. The program disarms interrupt 53 after target slant range has been updated.

The program next arms interrupt 54 which is connected to subroutine VIDEO. Interrupt 54 is generated by the range gate signal from the radar. The five-volt 30-usec range gate signal is patched into comparator C13 on the analog section of the CI-5000 where it is compared with a minus-three-volt signal. The false output of C13 on the logic section is patched to the clock input of delay flop DF05 whose enable input has been grounded. The arrival of the range gate signal causes the false output of C13 to change from minus-six-volts to zero-volts and trigger DF05. DF05 is set to stay enabled for ten-usec. The true output of DF05 is patched to interrupt trunk 54 where the ten-usec signal causes the computer program to execute subroutine VIDEO. It was necessary to execute VIDEO using the range gate interrupt due to the fact that the output voltage of the LOG IF amplifier is put into a holding circuit to retain the signal until the computer can sample it. The holding circuit has a certain amount of discharge, but knowing when the computer samples the output of the holding circuit allows the calibration curve of the LOG IF amplifier to be adjusted to account for the discharge factor and give correct values of received power.

It was intended to execute subroutine VIDEO at the pulse repetition frequency, PRF, of the radar which is variable from 800-1000-hz. The execution time of VIDEO is approximately 800-usec. However, the maximum

frequency at which it was possible to execute the subroutine was 250-hz. It was determined that the computer's inability to execute the subroutine at the PRF of the radar was due to the slowness of the computer's interrupt monitor system in processing and servicing interrupts. This slowness in interrupt processing was also responsible for the system's inability to use data-shift pulse rates much above 100-hz.

The first thing that occurs in VIDEO is an incrementation of the subroutine counter, K, by 1. The previously sampled value of LOG IF amplifier output voltage, V, is multiplied by 100. V is then compared with the operating characteristic curve, Figure (1). If V is less than -10.5 volts, the upper portion of the curve is used to calculate the received power relative to one milliwatt. From Equation (13):

$$PREL = -20 - (V + 10.5)20$$

The lower portion of the curve is used if V is greater than -11 volts. From Equation (12):

$$PREL = -77.5 - V(5.45) \quad .$$

The received power detected by the radar is calculated by Equation (17):

$$PREC = e^{(PREL/4.34)} \quad .$$

Target cross section is calculated using Equation (19):

$$\sigma_t = R_t^4(PREC)/K \quad .$$

The calculated value of target cross section is then added to a summing function, SIGSUM(2), and then loaded into the computer's A register. Target cross section is converted to an analog voltage on D/A channel #1

using machine language subroutine AD1DA1 which functions in a similar manner to ADODA1 for the AGC cross section computation mode. The instantaneous value of target cross section is displayed on an oscilloscope in the radar laboratory. AD1DA1 then samples the output voltage of the LOG IF amplifier on A/D channel #1 and stores this value for computation of target cross section the next time VIDEO is called.

After VIDEO has been executed 1000 times, interrupt 54 is disarmed and the average value of target cross section is computed by dividing SIGSUM(2) by 1000. The average value of target cross section is converted into an analog voltage on D/A channel #2 and displayed on an average cross section meter in the radar laboratory. The program then sequentially samples the test lines associated with control seitches C1, C2 and C3 to see if the radar operator has chosen another mode of operation. If this is not the case, the program returns to the LOG IF amplifier cross section computation mode.

IV. AREAS FOR IMPROVEMENT

The following items are suggested as areas for improvement:

1. The interrupt monitor system could be speeded up to allow processing of LOG IF amplifier cross sections on a pulse-to-pulse basis.

2. The program could be written in assembly language and speeded up by eliminating unneeded general features of various routines.

3. With the interrupt system and the program speeded up, cross section data and target track data could be processed on a time sharing basis. This way any changes in target aspect could be immediately correlated with any changes in cross section data.

4. The data transfer rate from the digital data buffer could be speeded up by the faster interrupt monitor system and/or by transferring the data bits directly into registers and then weighting the entire word.

5. A digital filtering algorithim could be employed to smooth out the target track data by averaging values of range, bearing and elevation.

6. Automatic scaling features for both cross section computation modes could be employed when tracking very small or weak targets. This could be done using the selector switch on the data buffer.

7. The processing of LOG IF amplifier cross section on a pulse-to-pulse basis would allow the cross section data to be analyzed for frequency content and occurence of magnitude. This could be done by making use of the fast fourier transform techniques available in the SDS-9300 and by histogram techniques. These concepts are extensively discussed in Refs. (5) and (6).

8. Removal of as many CI-5000 components as possible from the system should be accomplished to preclude system down time due to faulty components. A timing box in the radar room could take the place of the clock signals and the delay flops. The logic level changes performed by the comparators could be done in the radar room also.

V. CONCLUSIONS

The following conclusions were arrived at:

1. It is possible to interface the SDS-9300/CI-5000 hybrid computer system with the NIKE/AJAX radar system. The target parameters developed by the computer system from the target data sent from the radar system are of great value in coordinating changes in target aspect with changes in cross section magnitude.

2. It is possible to develop instantaneous and average cross section data from target AGC voltage. When the system was checked by tracking a sphere after calibration, the cross section data produced in the AGC mode was close to the actual sphere cross section.

3. It is possible to develop instantaneous and average cross section data from the LOG IF amplifier output voltage. The cross section values for this mode are not as accurate as those for the AGC mode.

```
      CØMMØN N,J,K,NRNG,NBD,NED,NR(18),NDEG(18),B(6),
     CSIGSUM(2),RNG
  101 FØRMAT(F8.1)
  102 FØRMAT(I5)
      READ(5,102)(NR(I),I=1,18)
      READ(5,102)(NDEG(I),I=1,18)
      READ(5,101)(B(I),I=1,6)
      CØNNECT (52,SHIFT1)
      CØNNECT (53,SHIFT2)
      CØNNECT (54,VIDEØ)
C     DISARM ALL INTERRUPTS
      IBITS=00000000B
S     EØM  033001
S     PØT IBITS
      CALL ENABLE
C     CALIBRATIØN RØUTINE
C     TEST FØR C1 ØN
S  10 SKS 031001
      GØ TØ 20
C     DISARM ALL INTERRUPTS
  200 IBITS=00000000B
S     EØM  033001
S     PØT IBITS
C     TEST FØR SS1 ØN
S     SKS 032020
      GØ TØ 11
C     CØNDUCT ZERØ CALIBRATIØN
  201 SIGMA=0.0
      AVESIG=0.0
      VR=0.0
      HR=0.0
      TAR=0.0
      XR=0.0
      YR=0.0
      TALT=0.0
```

```
      CALL DAC(1,SIGMA,2,AVESIG,6,VR,7,HR,8,TAR,9,XR,10,YR,
     C11,TALT)
C     TEST FØR SS2 ØN
S  11 SKS 032040
      GØ TØ 12
C     CØNDUCT INTERMEDIATE CALIBRATIØN
  202 SIGMA=0.1
      AVESIG=0.1
      HR=0.36
      TAR=0.36
      VR=0.25
      XR=0.03
      YR=0.03
      TALT=0.1
      CALL DAC(1,SIGMA,2,AVESIG,6,VR,7,HR,8,TAR,9,XR,10,YR,
     C11,TALT)
C     TEST FØR SS3 ØN
S  12 SKS 032100
      GØ TØ 20
C     CØNDUCT MAXIMUM CALIBRATIØN
  203 SIGMA=0.5
      AVESIG=0.5
      VR=0.5
      XR=-0.03
      YR=-0.03
      TALT=0.5
      CALL DAC(1,SIGMA,2,AVESIG,6,VR,9,XR,10,YR,11,TALT)
C     TARGET DATA RØUTINE
C     TEST FØR C2 ØN
S  20 SKS  031002
      GØ TØ 30
      N=0
      NRNG=0
      NED=0
      NBD=0
```

```
C     ARM INTERRUPT 52
      IBITS=40000000B
S     EØM  033001
S     PØT IBITS
   21 IF(N.LT.19) GØ TØ 21
C     DISARM INTERRUPT 52
      IBITS=00000000B
S     EØM  033001
S     PØT IBITS
C     CØNVERT RANGE, BEARING, AND ELEVATIØN TØ FLØATING
C     PØINT NUMBERS
      RNG=NRNG
      BD=NBD*0.05625
      ED=NED*0.05625
C     SCALE RANGE, BEARING AND ELEVATIØN FØR DISPLAY
C     IN THE CØMPUTER RØØM
      RR=RNG/100000.0
      BR=BD/1000.0
      ER=ED/1000.0
C     CØNVERT BEARING AND ELEVATIØN ANGLES TØ RADIANS
      BRAD=BD*6.28/360.0
      ERAD=ED*6.28/360.0
C     CØMPUTE ALTITUDE
      ALT=3.0*(((RNG*CØS(ERAD))**2)/1400000.0+RNG*SIN(ERAD))
      TALT=ALT/50000.0
C     CØMPUTE TARGET X AND Y CØØRDINATES
      TXN=RNG*CØS(ERAD)*SIN(BRAD)
      TYN=RNG*CØS(ERAD)*CØS(BRAD)
      XDIF=TXN-TXØ
      YDIF=TYN-TYØ
      TXØ=TXN
      TY9=TYN
      XR=TX9/2500000.0
      YR=TY9/2500000.0
C     CØMPUTE TARGET VELØCITY AND HEADING
```

```
      TD=SQRT(YDIF*YDIF+XDIF*XDIF)
      TV=TD*3600.0/2025.3
      VR=TV/2000.0
C     CØMPUTE TARGET HEADING
      Z=ABS(YDIF/XDIF)
      W=ATAN(Z)
      Y=W*360.0/6.28
      IF(XDIF.LT.0) GØ TØ 22
      IF(YDIF.GT.0) TH=90-Y
      IF(YDIF.LT.0) TH=90+Y
      GØ TØ 23
   22 IF(YDIF.GT.0) TH=270+Y
      IF(YDIF.LT.0) TH=270-Y
C     CØMPUTE TARGET ANGLE
   23 IF(BD.LT.180) LØS=BD+180
      IF(BD.GE.180) LØS=BD-180
      IF(TH.LT.LØS) TA=LØS-TH
      IF(TH.GE.LØS) TA=360-TH+LØS
      TAR=TA/1000.0
      HR=TH/1000.0
C     SEND TARGET DATA TØ RADAR RØØM
      CALL DAC(3,RR,4,BR,5,ER,6,VR,7,HR,8,TAR,9,XR,10,YR,
     C11,TALT)
C     CØMPUTE AGC CRØSS SECTIØNS
C     TEST FØR C3 ØN
S  30 SKS  031004
      GØ TØ 40
      SIGSUM(1)=0
      N=0
      NRNG=0
C     ARM INTERRUPT 53
      IBITS=20000000B
S     EØM  033001
S     PØT IBITS
   32 IF(N.LT.19) GØ TØ 32
```

```
C     DISARM INTERRUPT 53
      IBITS=00000000B
S     EØM  033001
S     PØT IBITS
      RNG=NRNG
      DØ 31 I=1,6000
      CALL AGC
   31 CØNTINUE
C     CØMPUTE AVERAGE AGC CRØSS SECTIØNS
      AVESIG=SIGSUM(1)/6000.0
      CALL DAC(2,AVESIG)
C     CØMPUTE VIDEØ CRØSS SECTIØNS
C     TEST FØR C4 ØN
S  40 SKS  031010
      GØ TØ 10
  206 K=0
      SIGSUM(2)=0
      N=0
      NRNG=0
C     ARM INTERRUPT 53
      IBITS=20000000B
S     EØM  033001
S     PØT IBITS
   42 IF(N.LT.19) GØ TØ 42
C     DISARM INTERRUPT 53
      IBITS=00000000B
S     EØM  033001
S     PØT IBITS
      RNG=NRNG*0.915
C     ARM INTERRUPT 54
      IBITS=10000000B
S     EØM  033001
S     PØT IBITS
   41 IF(K.LT.1000) GØ TØ 41
C     DISARM INTERRUPT 54
```

```
      IBITS=00000000B
S     EØM  033001
S     PØT IBITS
C     CØMPUTE AVERAGE VIDEØ CRØSS SECTIØNS
      AVESIG=SIGSUM(2)/1000.0
      CALL DAC(2,AVESIG)
      GØ TØ 10
      STØP
      END
```

```
      SUBRØUTINE SHIFT1
      CØMMØN N,J,K,NRNG,NBD,NED,NR(18),NDEG(18),B(6),
     CSIGSUM(2),RNG
      N=N+1
      IF(N.GT.18) GØ TØ 26
C     TEST FØR PRESENCE ØF RANGE BIT
S     SKS 031200
      GØ TØ 24
  220 NRNG=NRNG+NR(N)
C     TEST FØR PRESENCE ØF BEARING BIT
S  24 SKS 032001
      GØ TØ 25
  221 NBD=NBD+NDEG(N)
C     TEST FØR PRESENCE ØF ELEVATIØN BIT
S  25 SKS 032002
      GØ TØ 26
  222 NED=NED+NDEG(N)
   26 RETURN
      END
```

```
      SUBROUTINE SHIFT2
      COMMON N,J,K,NRNG,NBD,NED,NR(18),NDEG(18),B(6),
     CSIGSUM(2),RNG
      N=N+1
      IF(N.GT.18) GO TO 33
C     TEST FOR PRESENCE OF RANGE BIT
S     SKS 031200
      GO TO 33
  223 NRNG=NRNG+NR(N)
   33 RETURN
      END
```

```
      SUBROUTINE AGC
      COMMON N,J,K,NRNG,NBD,NED,NR(18),NDEG(18),B(6),
     CSIGSUM(2),RNG
C     COMPUTE CONSTRUCTIVE RANGE TO SPHERE
      AGC=AGC*100.0
      AGC2=AGC*AGC
      AGC3=AGC2*AGC
      AGC4=AGC3*AGC
      AGC5=AGC4*AGC
      RNGS=B(1)-B(2)*AGC+B(3)*AGC2-B(4)*AGC3+B(5)*AGC4-B(6)*
     CAGC5
      S=RNG/RNGS
      SIGMA=((S**2)**2)*(0.000036)
      SIGSUM(1)=SIGSUM(1)+SIGMA
S      LDP      SIGMA
C     DISPLAY COMPUTED TARGET CROSS SECTION
      CALL ADODA1
C     STORE SAMPLED VALUE OF AGC VOLTAGE
S      STD      AGC
      RETURN
      END
```

```
      SUBRØUTINE VIDEØ
      CØMMØN N,J,K,NRNG,NBD,NED,NR(18),NDEG(18),B(6),
     CSIGSUM(2),RNG
      K=K+1
      V=V*100.0
      IF(V.LT.(-10.5)) GØ TØ 43
      PREL=-77.5-V*5.45
      GØ TØ 44
   43 PREL=-20-(V+10.5)*20.0
   44 PREC=EXP(PREL*0.23)
      SIGMA=((RNG**2)**2)*PREC*0.000000000000252
      SIGSUM(2)=SIGSUM(2)+SIGMA
S      LDP     SIGMA
C     DISPLAY CØMPUTED TARGET CRØSS SECTIØN
      CALL AD1DA1
C     STØRE SAMPLED VALUE ØF LØG IF AMPLIFIER ØUTPUT
S      STD     V
      RETURN
      END
```

```
C       THIS IS A FAST D/A A/D ROUTINE USING D/A CHANNEL 1
C       AND A/D CHANNEL 0.  THIS ROUTINE WAS PREPARED BY
C       R. LIMES OF THE EE DEPT COMPUTER LAB STAFF,
X1       EQU      1
X2       EQU      2
A        EQU      5
B        EQU      4
$ADODA1  PZE
         STD      SVAB
         LDA      BRMFIN
         XMA      040
         STA      SV
         STZ      FIN
         EOM      034000
         POT      ADCW
         LDP      SVAB
         COPY     0777,(B,X2),(0,B)
         COPY     (X2,A),(A,X2)
         COPY     (-A,A)
         COPY     (X2,A),(A,X2)
         ARSD     0,2
         ETR      =077777000
         ADD      =1
         STA      DACOM
         SKN      FIN
         BRU      $-1
         STZ      FIN
         LDA      SV
         XMA      040
         XMA      041
         STA      SV
         EOM      035000
         POT      DACW
         SKN      FIN
         BRU      $-1
```

```
         LDA     SV
         STA     041
         LDP     ADBUF
         FLA     =0,
         MPØ     ADODA1
         BRR     ADODA1
CØN      FØRM    9,15
DACW     CØN     1,$+1
DACØM    PZE
         PZE
ADCW     CØN     1,$+1
ADCØM    CØN     0,ADBUF
         PZE
ADBUF    PZE
         PZE
SVAB     RES     2
SV       PZE
BRMFIN   BRM     INT
INT      PZE
         SKR     FIN
         BRU     $-1
         BRC     *INT
FIN      PZE
         END
```

```
C      THIS IS A FAST D/A A/D RØUTINE USING D/A CHANNEL 1
C      AND A/D CHANNEL 1.  THIS RØUTINE WAS PREPARED BY
C      R. LIMES ØF THE EE DEPT CØMPUTER LAB STAFF.
X1      EQU     1
X2      EQU     2
A       EQU     5
B       EQU     4
$AD1DA1 PZE
        STD     SVAB
        LDA     BRMFIN
        XMA     040
        STA     SV
        STZ     FIN
        EØM     034000
        PØT     ADCW
        LDP     SVAB
        CØPY    0777,(B,X2),(0,B)
        CØPY    (X2,A),(A,X2)
        CØPY    (-A,A)
        CØPY    (X2,A),(A,X2)
        ARSD    0,2
        ETR     =077777000
        ADD     =1
        STA     DACØM
        SKN     FIN
        BRU     $-1
        STZ     FIN
        LDA     SV
        XMA     040
        XMA     041
        STA     SV
        EØM     035000
        PØT     DACW
        SKN     FIN
        BRU     $-1
```

```
        LDA     SV
        STA     041
        LDP     ADBUF
        FLA     =0.
        MPØ     AD1DA1
        BRR     AD1DA1
CØN     FØRM    9,15
DACW    CØN     1,$+1
DACØM   PZE
        PZE
ADCW    CØN     1,$+1
ADCØM   CØN     1,ADBUF
        PZE
ADBUF   PZE
        PZE
SVAB    RES     2
SV      PZE
BRMFIN  BRM     INT
INT     PZE
        SKR     FIN
        BRU     $-1
        BRC     *INT
FIN     PZE
        END
```

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3. ABSTRACT

This thesis describes the design and use of a computer program for the real-time computation of radar cross section of a dynamic target using the NIKE/AJAX radar. The program is written specifically for use on the SDS-9300/CI-5000 hybrid computer system but could be adapted to other data processing systems. The input data consists of transmitted values of range, bearing and elevation from the NIKE/AJAX radar digital data buffer and sampled values of automatic gain control voltage and logrithmic amplifier output voltage from the NIKE/AJAX radar. Outputs include values of target range, bearing, elevation, velocity, heading, angle, X and Y positions, instantaneous values of target cross section and averaged values of target cross section. These computed quantities are converted into scaled voltages which are transmitted to displays in the radar laboratory. Although the system at this time provides only a basic real-time capability, it provides a foundation for further work planned in this area.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radar Cross Section						